CS250: FOUNDATIONS OF COMPUTER SYSTEMS [NETWORKING]

IP at Work: Fragments Assemble!
Packet's too big?
Fragment, transmit and
At receiving endpoint coalesce
If something goes awry?
The network shrugs does nothing
If *all* fragments do get through?
Coalesce with needlework so fine
That the transport can't spot the seams

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Frequently asked questions from the previous class survey

- Why does DHCP use two ports?
- Do closed networks only use the link layer?
- How do companies not end up manufacturing NICs with duplicate MAC addresses?
- What is included in a link layer frame's footer/trailer?
- How is data put back together?
- Are packets always the same size in WiFi networks?
- Why do data corruptions happen?
- Why don't personal computers have their own WiFi?

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Topics covered in today's lecture

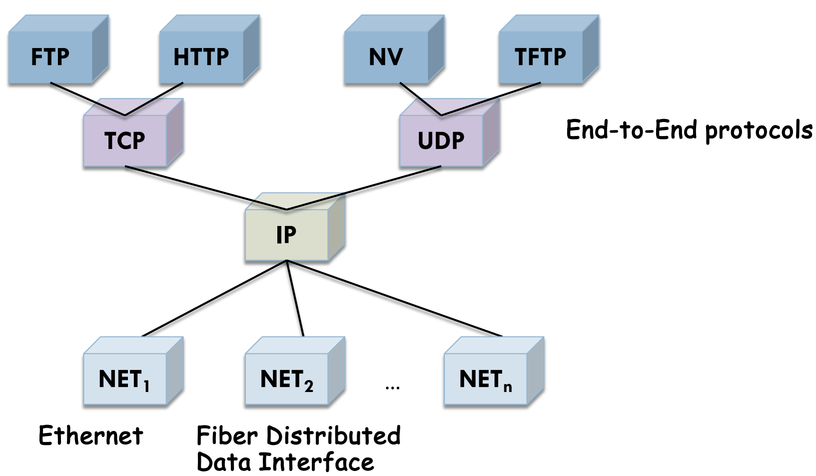
- IPv4
- IPv6

INTERNET ARCHITECTURE

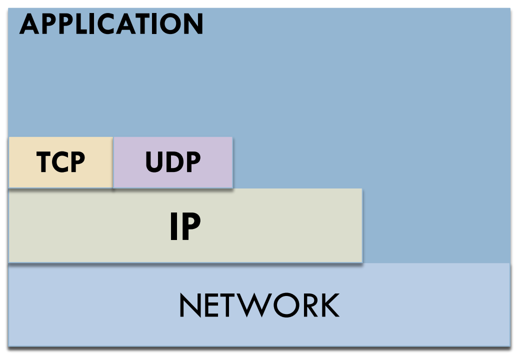
Internet architecture

- Evolved out of experiences with ARPANET
  - Funded by ARPA of the US DoD
- A **4-level** model

Internet protocol graph



Alternative view of the Internet Architecture



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Internet architecture

- Does not imply strict layering
  - Bypassing immediate lower layers is *possible*
- Layer has an **hour-glass** shape
  - Wide at top and bottom
  - Narrow in the middle
  - **IP** is the **focal point** of the architecture

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INTERNETWORKING

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Internetwork

- Arbitrary collection of **interconnected** networks
  - To provide some sort of host-host packet delivery service
- Network of networks
  - Made up of lots of smaller networks

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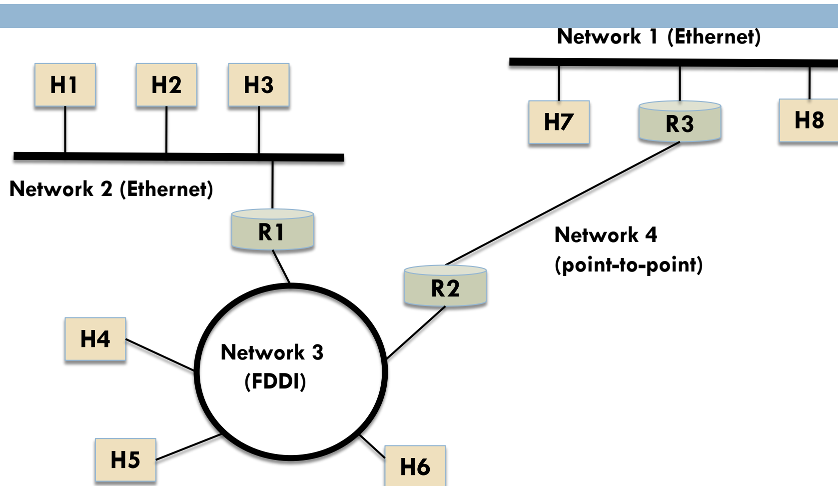
A simple internetwork

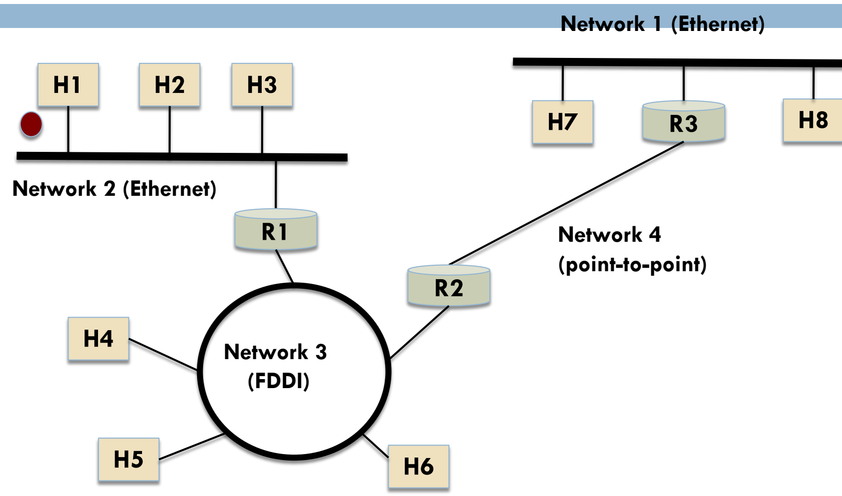


Fiber Distributed Data Interface (FDDI)

Internet Protocol (IP)

- Key tool to build scalable, **heterogeneous** networks
- Runs on all nodes (hosts and routers)
- Allows nodes and networks to *function as a single logical network*
- Possible to build an internetwork without IP
  - But IP is the only one that has faced **scale** issues

A simple internetwork: Communication between H1-H8



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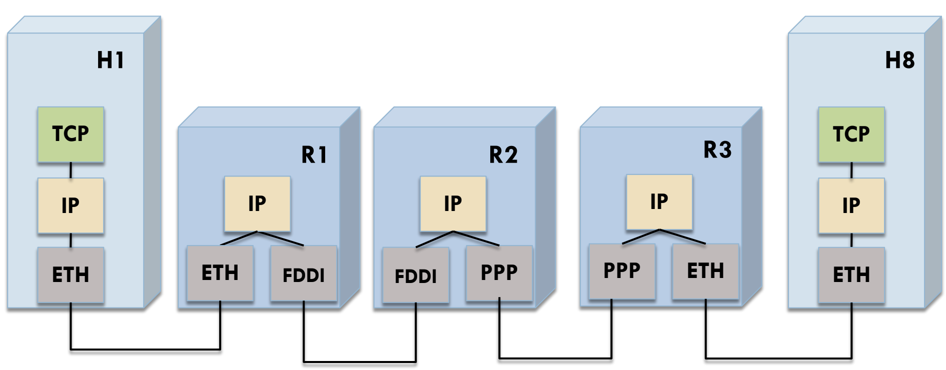
Example depicting how hosts (H1-H8) are logically connected



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The IP service model

- Datagram model of **delivery**
  - Connectionless
  - Best effort
- **Addressing** scheme
  - Identifies all hosts in the internetwork

Datagram delivery

- Datagram is a type of packet
  - Sent in a **connectionless** fashion
- No need for any *advance* setup mechanisms
  - That tell network what do when packet arrives
- Every datagram contains enough information
  - To forward packet to correct destination

The network makes a best effort to send datagrams across

- Things that could go **wrong** with the packets
  - Lost
  - Corrupted
  - Misdelivered
  - Out of order and duplicates
- When things go wrong, the network does **nothing**
  - No attempt to recover from the failure

Keeping routers simple was one of the original design goals of IP

- Important to **run over anything**
- Putting extra functionality into routers to make up for network deficiencies?
  - Not a good idea
- Higher-level protocols/apps that run above IP need to be aware of failure modes

The IP Packet format consists of a header followed by bytes of data

- Represented as a succession of **32-bit** words
- Packet formats designed to align on 32-bit boundaries
  - Simplifies task of processing in software
- Transmission order
  - ***Top word*** transmitted first
  - ***Leftmost byte*** of each word transmitted first

The IPv4 packet header

0	4	8	16	19	31
Version	HLen	TOS	Length		
Ident			Flags	Offset	
TTL		Protocol	Checksum		
SourceAddr					
DestinationAddr					
Options (variable)				Pad (variable)	
Data					

IP Packet format [1/5]

- **Version**
  - Makes it easy to **redefine** packet format later on
- **HLen**
  - Specifies length of header **in 32-bit words**
  - When there are no options (most of the time)
    - Header is **5 words** or 20 bytes
- **TOS** (type of service)
  - Allow packets to be treated differently
    - Based on application needs

IP Packet format [2/5]

- **Length**
  - Length of the datagram **in bytes**
  - Maximum size of IP datagram is 2^{16} bytes
- SECOND WORD OF IP PACKET
  - {Ident, Flags, Offset}
  - Information about **fragmentation**

IP Packet format [3/5]

- **TTL** (time to live)
  - Hop-count not timer (as originally intended)
- **Protocol** field
  - **Demultiplexing** key
    - Identifies higher-level protocol
    - TCP (6), UDP (17)
- **Checksum**
  - Consider IP header as a sequence of 16-bit words

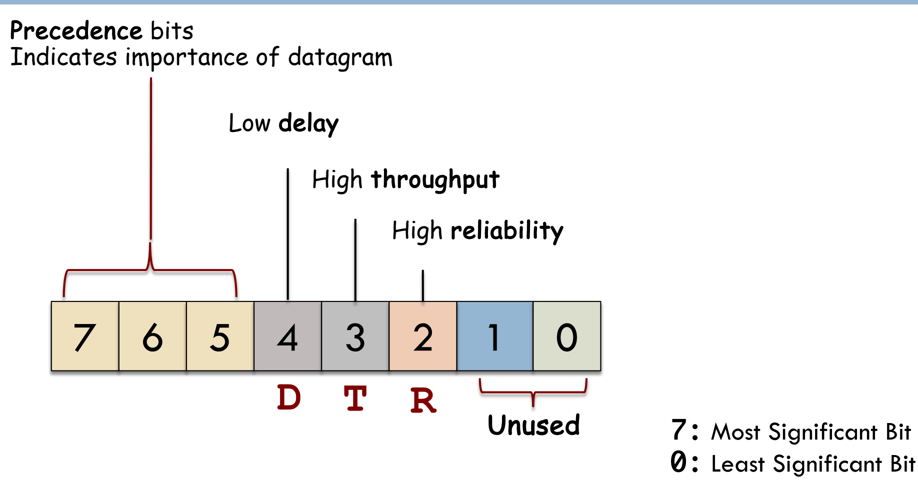
IP Packet format [4/5]

- **SourceAddr**
  - Decide if packet should be accepted
  - Also used for replies
- **DestinationAddr**
  - Full address of destination
  - Forwarding decisions are made at each router
- Presence or absence of **options**
  - Can be checked **based on size of Hlen** (without options header is 20 bytes)

IP Packet format [5/5]
TOS field {Type of Service}

- Meant to specify ***how*** the datagram should be ***handled*** as it traversed the internet
  - Preference for low delay
  - Preference for high throughput
  - Preference for high reliability
- In practice TOS was not widely implemented

The 8 bits allocated to TOS can be divided into 5 parts



Providing host-to-host service model over heterogeneous collection of networks

- Each network technology has its own idea of how large a packet can be
  - Ethernet v2: 1500 bytes
  - FDDI: 4352 bytes

Every network type has a Maximum Transmission Unit (MTU)

- Largest IP datagram that it can carry in its frame
- Smaller than the largest packet-size of network
  - IP datagram needs to fit in payload of **link-layer frame**

Ethernet Packet Layout

Bytes:	7	1	6	6	2	46 < Length < 1500	4
	Preamble	**S**	Destination address	Source address	Length Of data	Data for Transmission	Checksum

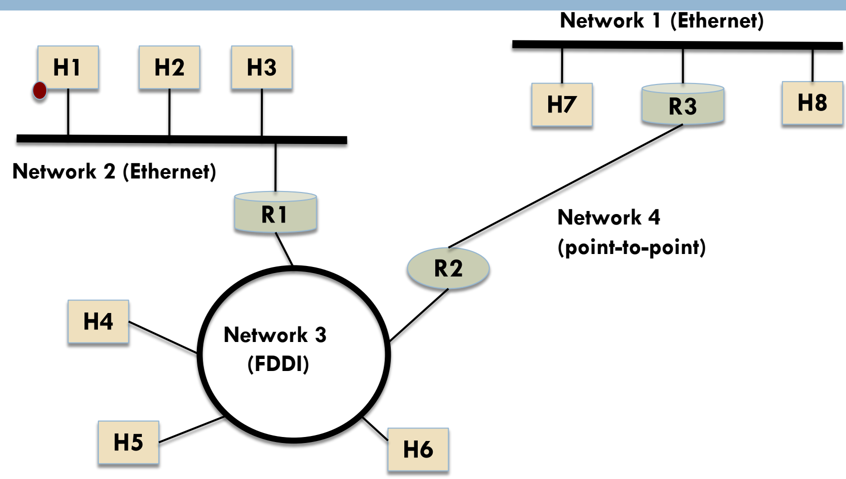
Preamble bit pattern: 10101010

Single Byte start (**S**) frame delimiter: 1010101**1**

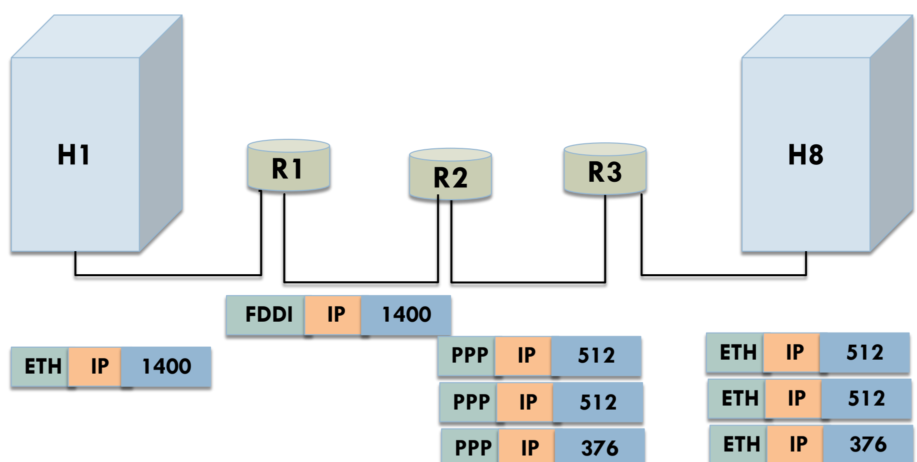
Fragmentation is necessary when datagram path includes network with smaller MTU

- All fragments carry same identifier in `Ident` field
  - To enable fragment reassembly
  - Chosen by the source host
- If all fragments do not arrive at receiving host?
  1. Receiver ***gives up*** reassembly [reassembly timeout: 15 seconds RFC0791]
  2. ***Discards*** fragments that did arrive
- IP **does not attempt** to recover from missing fragments

A simple internetwork: Sending IP datagrams from H1 to H8



IP datagrams traversing a sequence of physical networks



IPv4 Packet header

0	4	8	16	19	31
Version	HLen	TOS	Length		
Ident			Flags	Offset	
TTL		Protocol	Checksum		
SourceAddr					
DestinationAddr					
Options (variable)					Pad (variable)
Data					

Header fields used in IP fragmentation:
Fragmentation occurs at 8-byte boundaries

Start of header				
Ident = x	0	DF	0	Offset = 0
Rest of header				
1400 data bytes				

Unfragmented packet

Start of header				
Ident = x			1	Offset = 0
Rest of header				
512 data bytes				

Fragmented packet

Header fields used in IP fragmentation:

Fragmentation occurs at **8-byte boundaries**

Start of header				
Ident = x			1	Offset = 64
Rest of header				
512 data bytes				

Fragmented packet

Start of header				
Ident = x			0	Offset = 128
Rest of header				
376 data bytes				

Fragmented packet

IPV6 (AND COMPARING WITH IPV4)

IPv6 versus IPv4: Key Differences

- Source and destination addresses are **128-bits** (16 bytes) in IPv6
- IPv6 treats Options as **extension headers**
- To simplify processing of packets in routers, IPv6 **did away with fragmentation**
  - Responsibility for packet fragmentation is at the end points
  - IPv6 hosts must perform : (1) path MTU discovery, (2) perform end-to-end fragmentation, OR (3) send packets no larger than the default MTU=**1280**
- As of 2014, IPv4 still carried >99% of worldwide Internet traffic
  - In 2022, Google reported IPv6 accesses reaching ~40%

IPv6 Packet Header

0	4	8	12	16	19	31
Version	Traffic Class		Flow Label			
Payload Length				Next Header	Hop Limit	
SourceAddr [16 bytes]						
DestinationAddr [16 bytes]						

IPv6 Packet Header is fixed at 40 bytes ... So there is no Header Length

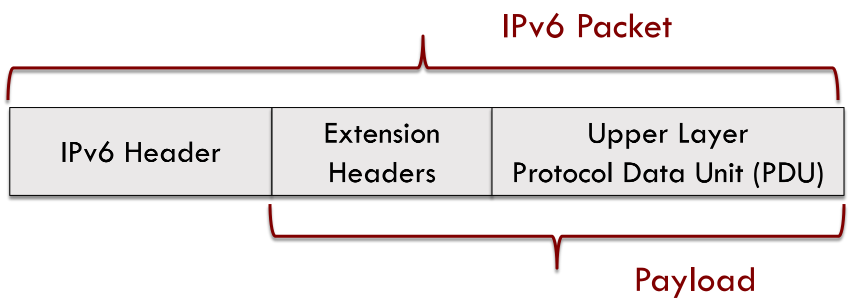
IPv6 Packet Header: Some more details [1/2]

- **Version**: 4 bits [0110]
- Traffic Class: 6+2 bits
  - Differentiated Services for QoS
  - Anything that ends in 2 "1" bits is intended for experimental or local use
- Flow Label (20 bits)
  - If it is non-zero: Serves as a hint to routers and switches with multiple outbound paths that these **packets should stay on the same path**, so that they will not be reordered
- Payload length (**16 bits**): Size of payload *including* extension headers

IPv6 Packet Header: Some more details [2/2]

- Next Header (8 bits)
  - Specifies the type of the next header
- Hop Limit (8 bits)
  - Replaces the time-to-live field of IPv4
- Destination and Source Addresses (**128-bits** or 16 bytes each)
  - The mass of earth is 2^{92} grams
- Note: The IPv6 packet **header has no checksum**
  - Transport or application layer protocols are assumed to provide sufficient error detection

Structure of the IPv6 Packet



PDU typically contains an upper layer protocol header and its payload.
For e.g.: a TCP segment, UDP Datagram, or an ICMPv6 message

Extension Header [1/2]

- If the `Next Header` field is non-zero
  - It defines an extension header
- Current extension header types
  - Information for routers, route definition, fragment handling, authentication, encryption, etc.
- Each extension header has a specific size and defined format

Extension Header [2/2]

- If an extension header is present?
  - **Follows** the basic header and **precedes** the payload AND
  - Includes a `Next Header`
- Every extension header starts off with the `Next Header`

IPv6 Extension Headers: The chain of pointers using the Next Header field

Each extension header must fall on a 64-bit (8-byte) boundary. Use Padding to get there if less than that.

IPv6 Header Next Header=6 (TCP)	TCP Segment

IPv6 Header Next Header=43 (Routing)	Routing Header Next Header=6 (TCP)	TCP Segment

IPv6 Header Next Header=43 (Routing)	Routing Header Next Header=51 (AH)	Authentication Header Next Header=6 (TCP)	TCP Segment

Fragmentation Header: 44

UDP
SIMPLE DEMULTIPLEXER

User Datagram Protocol

- **Simplest** possible transport protocol
  - Extends host-to-host into process-to-process communications
- No additional functionality to best-effort service provided by underlying network
- Adds **demultiplexing**
  - Allows applications on a host to **share** the service

UDP identification of processes

- Processes *indirectly* indentify each other
  - Abstract locator called **port**
- Source sends a message to a port
  - Destination receives messages from a port
- Process is identified by a port on a particular host

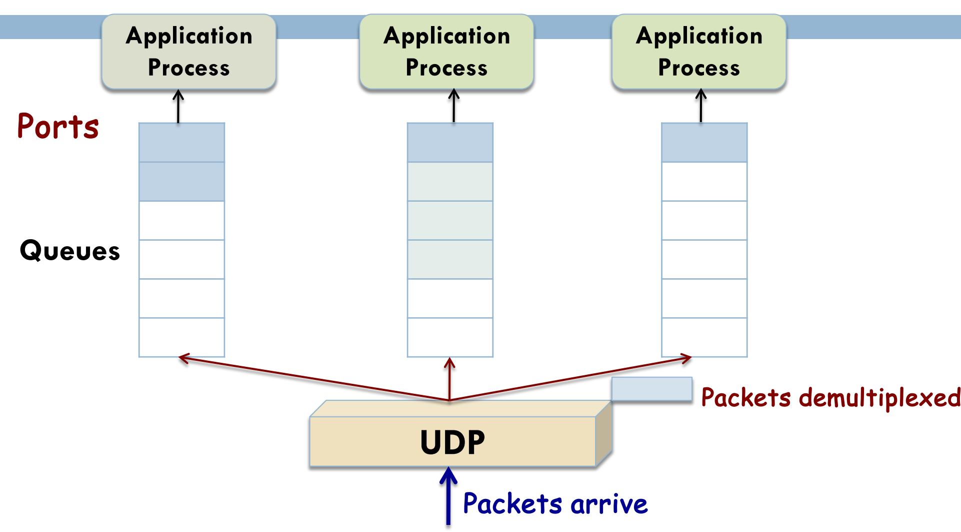
Format of a UDP header

0	16	31
SrcPort	DstPort	
Length	Checksum	
Data		

A port is just an abstraction

- Typically implemented as a **message queue**
- When message arrives?
  - Protocol appends message to end of the queue
- **UDP**
  - If the queue is full, message is discarded
  - No flow-control mechanism

UDP message queue: The port abstraction



Some work that UDP does do besides demultiplexing: Checksumming

- UDP header
- Message body
- ***Psuedoheader***: From the IP header
  - Protocol number
  - Source IP address
  - Destination IP address

  Verify if message is delivered between the correct endpoints
- UDP length
  - Used *twice*

The contents of this slide-set are based on the following references

- *Computer Networks: A Systems Approach. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8. [Chapter 1, 2]*
- Matthew Justice. *How Computers Really Work: A Hands-On Guide to the Inner Workings of the Machine*. ISBN-10/ISBN-13 : 1718500661/ 978-1718500662. No Starch Press. 2020. [Chapter 11]